

# Discovery of a nearby M9 dwarf

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## ABSTRACT

We report the discovery of a new M9.0 dwarf at only 8.2 pc, which we identified in our search for nearby ultracool dwarf ( $I - J \geq 3.0$ , later than M8.0) in the DENIS database. We measure a very high proper motion of 2.5 arc-sec/yr. The PC3 index measured from its low-resolution spectrum gives a spectrophotometric distance of 8.2 pc. This makes it the third closest M9.0 dwarf.

**Key words:** very low mass stars, brown dwarfs, individual star: DENIS 0334-49; LEHPM 3396.

## 1 INTRODUCTION

Nearby stars are the brightest representatives of their class, and therefore provide benchmarks for stellar physics. This is particularly true for intrinsically faint objects, such as white dwarfs, stars at the bottom of the main sequence, and brown dwarfs (BDs). In the last decade a significant number of nearby ultracool dwarfs have been identified by the DENIS (Epchtein 1997) and 2MASS (Skrutskie et al. 1997) surveys. On the DENIS side Delfosse et al. (2001) reported an M9 dwarf at 5 pc, and Martín et al. (1999) found a late-L dwarf at the same distance (DENIS-P J0255-4700, Martín et al. 1999; Cruz et al. 2003). Based on the 2MASS survey Burgasser et al. (2000) discovered a T5 dwarf at 10 pc (2MASS 0559-14, Dahn et al. 2002), and Teegarden et al. (2003) recently reported an M6.5 at only  $\sim 4$  pc. These very close ultracool dwarfs are much brighter than more distant objects and clearly easier to observe.

We are mining the DENIS database for nearby ultracool dwarfs, and have reported our intermediate results in several publications (e.g. Delfosse et al. 1997, Martín et al. 1999, Phan-Bao et al. 2001, 2003). Our search has a limiting distance of  $\sim 30$  pc, but ultracool dwarfs within 10 pc are obviously of particular interest. Here we report our detection of a M9.0 dwarf at only 8 pc, LEHPM 3396 or DENIS-P J033411.39-495333.6 (hereafter DENIS 0334-49)

Section 2 describes the observational data and their analysis, and Section 3 discusses our spectral type and distance estimates.

## 2 OBSERVATIONAL DATA

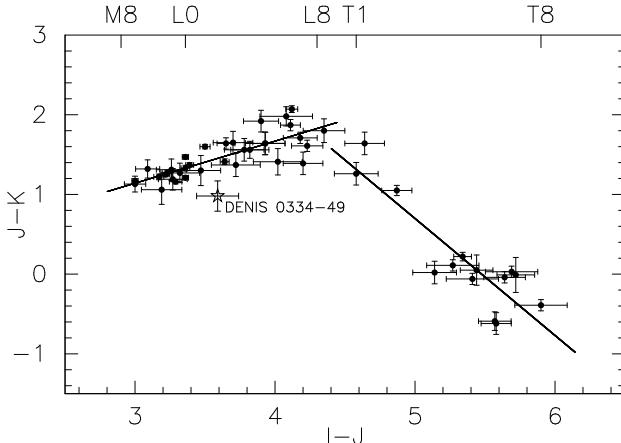
We selected DENIS 0334-49 in the DENIS database from its colours, which fall in the area of the ( $I - J$ ,  $J - K$ ) diagram occupied by very late-M and L dwarfs (Fig. 1). Fig. 2 shows its finding chart. We then proceeded to measure its proper motion, to discriminate against a distant giant of similar colour. DENIS 0334-49 appears on 4 plates in the collection of the Centre d'Analyse des Images (CAI, <http://www.cai-mama.obspm.fr/>): SERC-I, SERC-J, SERC-R and ESO-R. We digitized these survey plates with the MAMA microdensitometer Berger et al. (1991) at CAI, and analysed the resulting images with SExtractor (Bertin & Arnouts 1996). We calibrated these measurements using the ACT (Urban, Corbin & Wycoff 1998) catalogue (Postman et al. 1997) as astrometric reference and the GSPC-2 (Bucciarelli et al. 2001) catalogue as photometric reference. A least-square fit to these 4 positions and the DENIS and 2MASS positions determines an absolute proper motion of 2.5 arc-sec/yr, over a baseline of 22 years. At this point we realized that DENIS 0334-49 had been previously identified as a high proper motion star by Pokorny et al. (2004), under LEHPM 3396. Table 1 sum-

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**Table 1.** Coordinates at the DENIS epoch, photometry and astrometry of DENIS 0334–49

$\alpha$ (2000.0)	$\delta$ (2000.0)	Epoch	B	R	I	J	K	$\mu_\alpha$ ( $''$ /yr)	$\mu_\delta$ ( $''$ /yr)	$\mu_{\text{total}}$ ( $''$ /yr)
03 34 11.39	–49 53 33.6	1996.937	20.5 ±0.3	17.5 ±0.2	14.90 ±0.05	11.31 ±0.10	10.33 ±0.09	2.35 ±0.03	0.47 ±0.03	2.50 <sup>a</sup> ±0.03

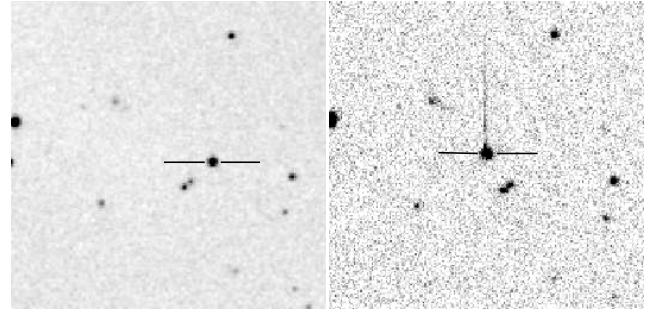
<sup>a</sup> : previously known as a high proper motion star, as LEHPM 3396 in Pokorny et al. (2004)



**Figure 1.**  $I_C - J$ ,  $J - K_S$  diagram for 48 ultracool dwarfs ( $I_C - J \geq 3.0$ ); most photometric data from Phan-Bao et al. (2003), Dahn et al. (2002), Reid et al. (2001), Burgasser et al. (2003) and references therein. The distinct M/L and T sequences are clearly visible.

marizes the photometry and astrometry of DENIS 0334–49. With  $I = 14.90$  and its very high proper motion, DENIS 0334–49 has a reduced proper motion well above the maximum reduced proper motion for an M giant of the same color (Phan-Bao et al. 2003). This makes it a certain dwarf, and a nearby one. From an  $M_J$  vs.  $I - J$  relation, calibrated by 48 single M ( $\geq M8.0$ ), L, and T dwarfs with known trigonometric parallaxes and good photometry (Phan-Bao et al., in preparation), we estimated a preliminary distance of  $5.5 \pm 0.8$  pc.

We observed DENIS 0334–49 in September 2005 with the DBS spectrograph on the 2.3m telescope at Siding Spring Observatory. The 158g/mm grating provided a wavelength coverage of 580–1030 nm at 0.5 nm resolution. The data were reduced using FIGARO. Smooth spectrum stars were observed at a range of airmass to remove the telluric lines using the technique of Bessell (1999). The EG131 (Bessell 1999) spectrophotometric standard was used for relative flux calibration, and a NeAr arc provided the wavelength calibration. All spectra were normalized over the 754–758 nm interval, the denominator of the PC3 index Martín et al. (1999) and a region with a good flat pseudo-continuum. Figure 3 shows the resulting spectrum of DENIS 0334–49, together with two comparison stars. The M8.0 standard (VB 10) was observed in the same configuration, and the M9.0 dwarf (DENIS-P J1431–1953) was observed by Martín et al. (1999) with a similar resolution. It is clear from the figure that the spectrum of DENIS 0334–49 is steeper than that of VB10.



**Figure 2.** Archival images of DENIS 0334–49: SERC-I (left, epoch: 1984.915) and DENIS-I (right, epoch: 1996.937). The size of each image is  $3.2' \times 3.2'$ , and North is up and East to the left.

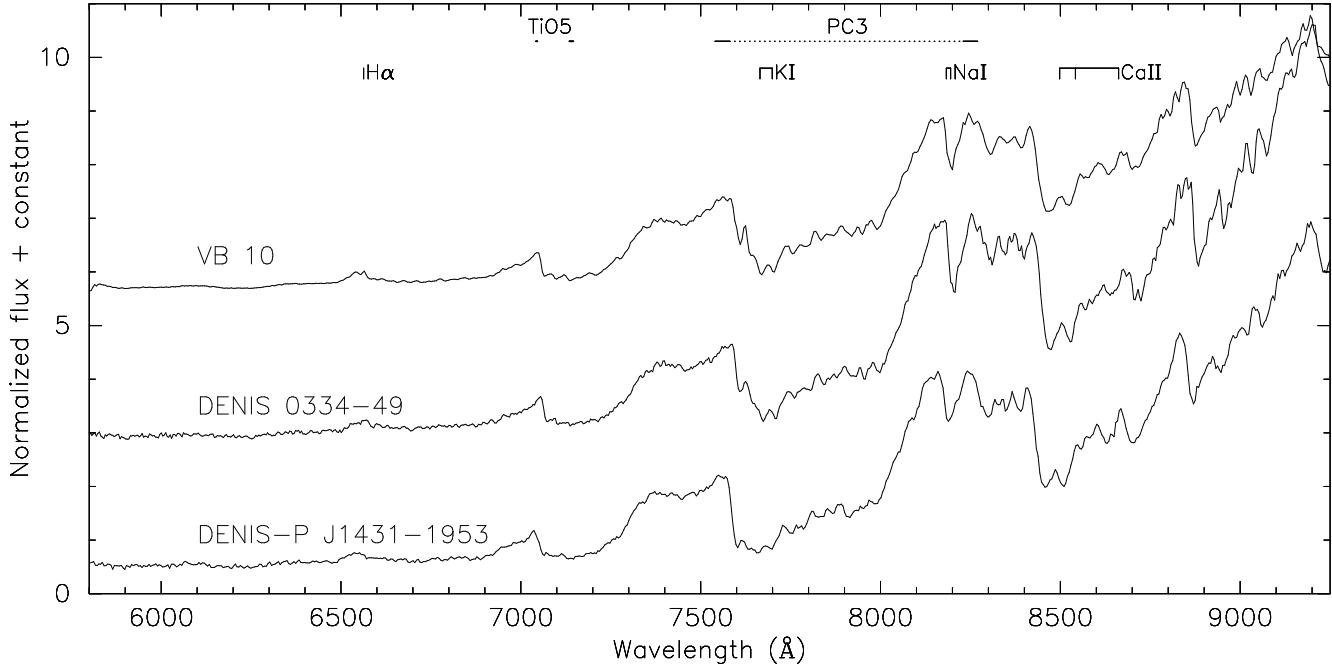
At the resolution of the spectrum, M dwarfs are immediately distinguished from M giants by the presence of the NaI and KI doublets, the presence of FeH bands, the appearance of strong CaH cutting into the continuum shortward of 700 nm, and by the absence of the CaII triplet (e.g. Bessell 1991).

### 3 DISCUSSION

Table 2 lists our spectral type estimates for DENIS 0334–49, based on the Martín et al. (1999) calibration of the PC3 index and the Cruz & Reid (2002) calibration of the TiO5 index. Since the TiO5 index wraps around at spectral type  $\sim M7$ , we used the spectral type derived from the PC3 index to choose between the two branches of the Cruz & Reid (2002) calibration. The V0a index saturates before the spectral type of DENIS 0334–49 and we therefore did not use it. We average the spectral types computed from the useful two indices to adopt a classification of  $M9.0 \pm 0.5$ , consistent as well with visual comparison with the classification standards.  $H_\alpha$  is not detected, and we used the SPLIT IRAF task to measure an upper limit of 2.5 Å to its equivalent width. Given the weak continuum at 656 nm, this represents a strong limit on  $H_\alpha$  emission.

To estimate the distance of DENIS 0334–49 we have extended the Crifo et al. (2005) PC3 vs. absolute magnitude calibration to higher PC3 index values, adding LP 944-20 and BRI 0021-0214 (respectively M9.0 and M9.5, and both with data from Dahn et al. 2002 and Geballe et al. 2002) to their 12 stars later than M7.0. Fig. 4 shows the resulting PC3 to absolute magnitude relations for the  $I$ ,  $J$ , and  $K$  bands. The following cubic least-square fits to those data:

$$M_I = -61.747 + 105.214(PC3) - 48.773(PC3)^2$$



**Figure 3.** Spectrum of DENIS 0334–49 (M9, this paper), VB10 (M8, Kirkpatrick, Henry & McCarthy 1991); and DENIS-P J1431–1953 (M9, Martín et al. 1999). The positions of the H $\alpha$ , NaI, KI and CaII lines are indicated, as well as the spectral intervals used to compute the TiO5, and PC3 indices.

**Table 2.** Estimated absolute magnitude, spectrophotometric distance for DENIS 0334–49 and VB 10

Stars	PC3	TiO5	Sp.T (PC3)	Sp.T (TiO5)	Sp.T (adopted)	$M_I$	$M_J$	$M_K$	$d_I$ (pc)	$d_J$ (pc)	$d_K$ (pc)	$d_{sp}$ (pc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
DENIS 0334–49	2.41	0.416	M9.8	M8.6	M9.0	15.23	11.92	10.71	8.6	7.5	8.4	8.2
VB 10	1.87	0.307	M8.1	M8.0	M8.0	14.29 <sup>b</sup>	11.24 <sup>b</sup>	10.10 <sup>b</sup>	5.1	5.5	5.5	5.4 <sup>a</sup>

<sup>a</sup> :  $d_\pi = 5.87$  pc, derived from  $\pi = 170.3$  mas for its proper motion companion HIP 94761

<sup>b</sup> : optical and infrared photometry from Bessell (1991)

*Column 1:* Star name. *Columns 2 & 3:* Spectroscopic indices. PC3 defined in Martín et al. (1999) and TiO5 in Reid, Hawley & Gizis (1995). *Columns 4, 5 & 6:* Spectral types derived from the PC3 and TiO5 index using the formula given in Martín et al. (1999) and Cruz & Reid (2002). *Columns 7, 8 & 9:* Absolute magnitudes for the  $I$ ,  $J$ ,  $K$  bands based on the PC3-absolute magnitudes relation. *Columns 10, 11 & 12:* Distance (pc) estimated from the DENIS photometry and the  $M_I$ ,  $M_J$ ,  $M_K$  derived from the PC3 index. *Column 13:* Adopted distance.

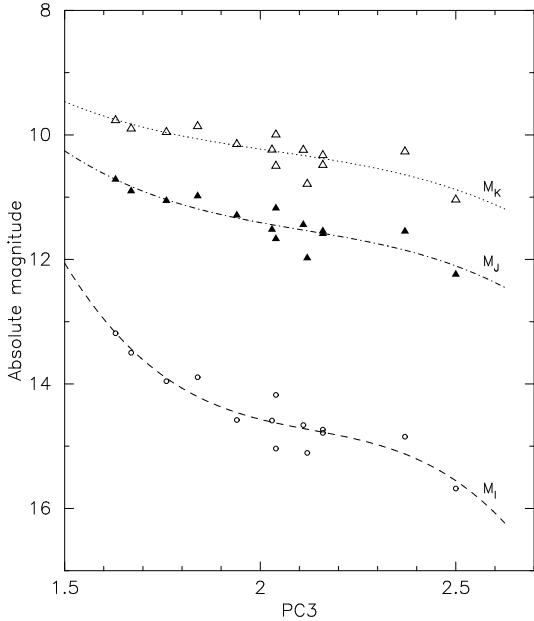
$$\begin{aligned}
 & +7.622( \text{PC3} )^3 & (1) \\
 M_J & = -16.549 + 37.791( \text{PC3} ) - 17.404( \text{PC3} )^2 & \\
 & + 2.749( \text{PC3} )^3 & (2) \\
 M_K & = -7.543 + 24.336( \text{PC3} ) - 11.479( \text{PC3} )^2 & \\
 & + 1.877( \text{PC3} )^3 & (3)
 \end{aligned}$$

are valid for  $1.63 \leq \text{PC3} \leq 2.50$ , or spectral types between M7.0 and M9.5. Over this range the rms dispersion of the data around these fits is approximately 0.2 magnitude, corresponding to a 10% standard error on distances to single stars.

Table 2 lists the absolute magnitudes for the three DENIS bands computed from the PC3 index, as well as the corresponding spectrophotometric distance estimates and their average ( $8.2 \pm 0.8$  pc). The values for the three colours  $I$ ,  $J$ ,

$K$  are very similar, indicating correlated uncertainties for the three estimators. As usual, these distances would be underestimated by up to  $\sqrt{2}$  if DENIS 0334–49 is in fact an unresolved binary.

DENIS 0334–49 has a redder  $I - J$  color,  $I - J = 3.59$ , than the  $I - J \sim 3.3$  of a typical M9.0 dwarf, (Leggett 1992). Comparison with the DENIS color of well known M9 dwarfs (Table 1 of Phan-Bao et al. 2003), shows that DENIS 0334–49 is much redder at  $I - J$  than DENIS 1048–39 but more similar to LP 944-20 (M9,  $I - J = 3.27$ ) or BRI 0021-02 (M9.5,  $I - J = 3.26$ ); both of these are young. Additionally, with a high PC3 index the DENIS 0334–49 absolute magnitudes estimated from the calibration as given above are  $\sim 0.4$  magnitude fainter than that of a typical M9 dwarf but consistent with that of a young M9 field



**Figure 4.** The PC3 index vs. absolute magnitudes in the Cousins *I* and CIT *JK* passbands for 14 M dwarfs with spectral types ranging from M7 to M9.5, see Sec. 3.

brown dwarf; raising the possibility that DENIS 0334–49 might be a brown dwarf and suggesting that a lithium test (Martín, Rebolo & Magazzù 1994) will be of interest. If this is the case, its distance of 8.2 pc makes DENIS 0334–49 the 3<sup>rd</sup> nearest M9.0 dwarf in the immediate solar neighbourhood, after LP 944-20 (5 pc) and DENIS 1048–39 (5.2 pc), and formally before LHS 2065 (8.5 pc). One should note that in the case of an old M9 field dwarf ( $M_J = 11.45$ , Dahn et al. 2002) a derived distance of 9.4 pc would place DENIS 0334–49 the 5<sup>th</sup> closest M9.0, after LHS 1070C ( $d = 8.8$  pc, Leinert et al. 2000). It is an obvious target for a trigonometric parallax measurement, and a good benchmark ultracool dwarf.

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